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Patent Application

of

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for

A SYSTEM AND METHOD FOR THE GENERATION OF A PARTLY SYNTHESIZED HIGH-QUALITY SIGNAL FOR ACCELERATION OF AN ARMATURE OF AN ELECTRIC DRIVE

Field of the Invention

[0001] The invention relates to a method and system for controlling rotary or linear electric drives. More particularly, the invention relates to a system and method for the generation of a partly synthesized signal of high dynamic quality to control the acceleration of an armature (rotary or linear) of an electric drive.

Background of the Invention

[0002] In order to design high-quality position or speed control for a rotary or linear electric drive it has been customary in the past to control the components directly generating torque or force in the innermost loop, that is, in cascade control. The most recent developments have shown that on the other hand it is highly advantageous not to control the torque or force generating components of the current volume indicators indirectly, but to guide the acceleration of the part propelled, that is, in cascade control. In the case of rotary drives this is the spin of the rotor, and in the case of linear drives it is the linear acceleration of the armature. Hence, use of an accelerometer is required for registration of these values.

[0003] One type of accelerometer that may be used, for example, is an accelerometer which operates on the Ferraris principle. These types of accelerometers have certain deficiencies though. This type of accelerometer, on the whole, is characterized by a delay in measurement, albeit a small one. Another deficiency is that this accelerometer can never be completely rigidly connected to the place engaged by rotary thrust in the case of a rotary drive, or by linear thrust in the case of a linear drive. The result of these two facts is that loop limit cycles and/or self-excited oscillations are formed in the cascade control loop for the acceleration.

[0004] Unless these limit cycles and/or self-excited oscillations are prevented, use of such a cascade control loop is not successful for high-quality position or speed control. A method for suppression of these limit cycles and/or self-excited oscillations in the cascade control loop for acceleration has been proposed for rotary drives. However, this process has the disadvantage that its application is extremely costly and that it reacts with extreme sensitivity to fluctuations in the parameters of the drive. Thus, a need exists for a low cost system and method for cascade controlling the acceleration of an armature of an electric drive that is insensitive to drive fluctuations, and prevents limit cycles and/or self-excited oscillations in

the cascade acceleration control loop.

Summary of the Invention

[0005] It is therefore an object of the invention to provide a system and method for controlling the acceleration of an armature of an electric drive by generating a high quality acceleration error correction signal $\underline{z}$, the system comprising an accelerometer for obtaining a measured armature acceleration value $\underline{b}_m$, which is equal to the product of a true armature acceleration α, and an acceleration measurement transfer function $F_g(p)$, and means for obtaining a measured acceleration signal, $\underline{b}_{Em}$, which is generated from a measured substitute acceleration signal $\underline{b}_E$. $\underline{b}_m$ and $\underline{b}_{Em}$ are scaled such that the relationship of $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g(p)$ is satisfied. The measured armature acceleration signal $\underline{b}_m$ is filtered with a first filter transfer function of $F_T(p)$, and the measured acceleration signal $\underline{b}_{Em}$ is filtered with a second filter transfer function of $F_H(p)$. The first and second filter outputs are combined to form the partly synthesized high quality acceleration error correction signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet F_H(p)$.

Brief Description of the Drawings

[0006] The novel features and advantages of the present invention will best be understood by reference to the detailed description of the preferred embodiments which follows, when read in conjunction with the following drawings, in which:

[0007] Fig. 1 illustrates a control system for a plurality of electric drive types, in accordance with an embodiment of the invention;

[0008] Fig. 2 illustrates a control system for a plurality of electric drive types, in accordance with a first alternative embodiment of the invention;

[0009] Fig. 3 illustrates a control system for a plurality of electric drive types, in

accordance with a second alternative embodiment of the invention; and

[0010] Fig. 4 illustrates a control system for a plurality of electric drive types, in accordance with a third alternative embodiment of the invention.

Detailed Description of the Preferred Embodiments

[0011] The various features of the preferred embodiments will now be described with reference to the drawings, in which like parts are identified with the same reference characters. The following description of the presently contemplated best mode of practicing the invention is not to be taken in a limiting sense, but is provided merely for the purpose of describing the general principles of the invention.

[0012] For the purpose of generating a high-quality signal for acceleration of an electric drive, the acceleration signal, $\underline{b}_m = \alpha \bullet F_g(p)$ (in which $F_g(p)$ describes the measurement transfer function), is first registered (or measured), and then the torque $\underline{m}$, or the propulsive force f, as substitute acceleration signal $\underline{b}_{Em} = \underline{m}$ or $\underline{b}_{Em}$ = f is scaled. In scaling the acceleration signal $\underline{b}_{Em}$, all losses arising throughout propulsion are disregarded and the convention is adopted that an absolutely rigid connection of the surface engaged by the thrust of the drive to the place at which the effect used for registration of acceleration is used. The result is that the relation $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g\,(p)$ is satisfied.

[0013] The acceleration signal $\underline{b}_m = \alpha \bullet F_g(p)$, is input to a low-pass filter with the low-pass transfer function $F_T(p)$; hence the signal $\underline{x} = \underline{b}_m \bullet F_T(p)$ is present at the output of the filter. The substitute acceleration signal ($\underline{b}_{Em}$) is input to a high-pass filter with the high-pass transfer function $F_H(p)$, which satisfies the relationship of $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$ The output of filter 3 is the signal $\underline{y} = \underline{b}_{Em} = \alpha \bullet F_g(p) \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$. Lastly, the synthesized signal $\underline{x} + \underline{y}$ is formed; it is used as a substitute signal of high dynamic quality for the instantaneous armature acceleration value in automatic control of the drive.

[0014] For this purpose, in the case of rotary current propulsion the rotary acceleration α of the rotated armature is registered metrologically by an accelerometer 30 connected to the armature and preferably operating on the Ferraris principle, and is consequently available as measured acceleration signal $\underline{b}_m = \alpha \cdot F_g(p)$. $F_g(p)$, with $F_g(0) = 1$, here represents the so-called measurement transfer function of the accelerometer 30. The torque $\underline{m}$ of the electric drive 20, hereafter designated as substitute acceleration signal $\underline{b}_E = \underline{m}$, is also measured and accordingly is available as measured substitute acceleration signal $\underline{b}_E = \underline{m}$. As is to be immediately perceived, use may of course be made, without impairing the operation of the device claimed for the invention, in place of the torque $\underline{m}$ of the drive, of the torque-forming transverse-current components $\underline{i}q$ of the current volume indicator of the rotary current fed winding of the drive 20 as substitute acceleration signal $\underline{b}_E = \underline{i}q$.

[0015] In what follows, as is customary in control engineering, it is assumed that both the measured acceleration signal $\underline{b}_m$, and on the other measured substitute acceleration signal $\underline{b}_{Em}$, all losses occurring in the drive in question are disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $\underline{b}_m = \alpha \cdot F_g(p) = \underline{b}_{Em} \cdot F_g(p)$ is satisfied. The measured acceleration signal $\underline{b}_m$ is delivered to the input of a low-pass filter with the low-pass transfer function $F_T(p)$, with $F_T(0)$ preferably equaling 1. Hence the signal $\underline{x} = \underline{b}_m \cdot F_T(p)$ can be received at the output of the low-pass filter. The measured substitute acceleration signal $\underline{b}_{Em}$ is delivered to the input of a high-pass filter with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \cdot F_g(p)$. Consequently, the signal $\underline{y} = \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ may be received at this high-pass filter. A signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ is now formed in accordance with the relation $\underline{z} = \underline{x} + \underline{y}$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the

undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question.

[0016] In the case of a traveling-wave drive, the linear acceleration α of an armature in linear movement is measured by means of an accelerometer mechanically connected to this armature, one preferably operated on the Ferraris principle transposed to linear movement, and is accordingly available as measured acceleration signal $\underline{b}_m = \alpha \bullet F_g(p)$. In this instance $F_g(p)$, with $F_g(0) = 1$, represents the so-called measurement transfer function of the accelerometer. The linear force f of the drive, to be designated in what follows as substitute acceleration signal $\underline{b}_E = f$, is also measured and is accordingly available as measured substitute acceleration signal $\underline{b}_{Em}$. As is to be immediately perceived, without impairing the operation of the device claimed for the invention, the transverse-current component $\underline{i}q$ immediately forming the linear force of the current volume indicator of the multiphase current-fed winding of the drive may be used as substitute acceleration signal $\underline{b}_E = \underline{i}q$.

[0017] It is assumed in what follows, as is customary in control engineering, that both the measured acceleration signal $\underline{b}_m$ and the substitute acceleration signal $\underline{b}_{Em}$, all losses occurring in the drive in question are disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g(p)$ is satisfied.

[0018] The measured acceleration signal $\underline{b}_m$ is delivered to the input of a low-pass filter with the low-pass transfer function $F_T(p)$, with $F_T(0)$ preferably equaling 1. Hence the signal $\underline{x} = \underline{b}_m \bullet F_T(p)$ can be received at the output of the low-pass filter. The measured substitute acceleration signal $\underline{b}_{Em}$ is delivered to the input of a high-pass filter with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$. Consequently, the signal $\underline{y} = \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet$

$F_g(p)]$ may be received at the output of this high-pass filter. A signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ is now formed in accordance with the relation $\underline{z} = \underline{x} + \underline{y}$. This synthesized signal is subsequently used as a very high-quality dynamic substitute for the undelayed instantaneous value of rotary acceleration α of the rotated armature in automatic control of the drive in question.

[0019] In the case of direct-current propulsion the rotary acceleration α of the rotated armature is measured by an accelerometer connected to this armature and preferably operating on the Ferraris principle, and is consequently available as measured acceleration signal $\underline{b}_m = \alpha \bullet F_g(p)$. $F_g(p)$, with $F_g(0) = 1$, here represents the so-called measurement transfer function of the accelerometer. The torque m of the drive, hereafter designated as substitute acceleration signal $\underline{b}_E = \underline{m}$, is also measured and accordingly is available as measured substitute acceleration signal $\underline{b}_{Em}$. As is to be perceived immediately, use may of course be made directly, without impairing the operation of the device claimed for the invention, in place of the torque m of the drive, of the armature current $\underline{i}_a$ of the direct-current fed winding of the drive as substitute acceleration signal $\underline{b}_E = \underline{i}_a$.

[0020] It is assumed in what follows, as is customary in control engineering, that both the measured acceleration signal $\underline{b}_m$ and the substitute acceleration signal $\underline{b}_{Em}$, all losses occurring in the drive in question are disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g(p)$ is satisfied.

[0021] The measured acceleration signal $\underline{b}_m$ is delivered to the input of a low-pass filter with the low-pass transfer function $F_T(p)$, with $F_T(0)$ preferably equaling 1. Hence the signal $\underline{x} = \underline{b}_m \bullet F_T(p)$ can be received at the output of the low-pass filter. The measured substitute

acceleration signal $\underline{b}_{Em}$ is delivered to the input of a high-pass filter with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$. Consequently, the signal $\underline{y} = \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ may be received at the output of this high-pass filter. A signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ is now formed in accordance with the relation $\underline{z} = \underline{x} + \underline{y}$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question.

[0022] The device and the process for obtaining a partly synthesized signal of high dynamic value for acceleration of the armature of a machine is explained in detail in what follows on the basis of an example of a separately excited direct-current machine and with reference to the drawings in Figures 1 to 4.

[0023] It is advantageous in the design of a high-quality position or speed control for a separately excited direct-current machine to control rotary acceleration of the armature rather than the armature current in the innermost loop. For this purpose, the rotary acceleration α of the rotor is measured by an accelerometer, preferably one operating on the Ferraris principle, and is accordingly available as measured rotary acceleration $\underline{b}_m = \alpha \bullet F_g(p)$. Block 1 (see Figures 1, 2, 3, and 4) with transfer function $F_g(p)$, with $F_g(0) = 1$, describes the so-called measurement frequency response of the accelerometer 30. The torque $\underline{m}$ of the drive 20, which in what follows is designated as substitute acceleration signal $\underline{b}_E = \underline{m}$, is also measured and accordingly is available as measured substitute acceleration signal $\underline{b}_{Em}$. Armature current $\underline{i}_a$ of the direct-current-fed armature winding of the drive may, of course, also be used as substitute acceleration signal $\underline{b}_E = \underline{i}_a$ in place of the moment $\underline{m}$ of the drive.

[0024] It is assumed, in what follows, as is customary in control engineering, that both the measured acceleration signal $\underline{b}_m$ and the measured substitute acceleration signal $\underline{b}_{Em}$, all losses occurring in the drive in question are disregarded and a mechanically absolutely rigid

connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g(p)$ is satisfied.

[0025] The measured acceleration signal $\underline{b}_m$ is delivered to the input of a low-pass filter 2 (see Figures 1, 2, 3, and 4) with the low-pass transfer function $F_T(p)$, with $F_T(0)$ preferably equaling 1. Hence the signal $\underline{x} = \underline{b}_m \bullet F_T(p)$ can be received at the output of the low-pass filter 2. The measured substitute acceleration signal $\underline{i}_{bm}$ is delivered to the input of a high-pass filter 3 (see Figures 1 and 2) with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$. Consequently, the signal $\underline{y} = \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ is output from the high-pass filter 3.

[0026] A signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet [F_T(0) - F_T(p) \bullet F_g(p)]$ is now formed in accordance with the relation $\underline{z} = \underline{x} + \underline{y}$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question. The difference between the set value $\propto_{soll}$ assigned by a superimposed control system and the synthesized signal $\underline{z}$ is delivered to a suitable control unit 4 as control difference (see Figure 1). Delay of the measurement transfer function $F_g(p)$ and the considerable disturbance of the transfer function $F_M(p)$ are eliminated from the control frequency response, which is of decisive importance for stability, possible limiting cycles, and self-excited oscillations.

[0027] The last-named transfer function, $F_M(P)$, describes the mechanical frequency response between the surface of the armature moved which is engaged by the thrust of the drive and the position of the moved part of the accelerometer at which the effect used for registration of acceleration is generated. The low-pass filter with low-pass transfer function $F_\gamma(p)$ almost entirely eliminates the influence of this mechanical frequency response. So long as transfer function $F_M(p)$ does not deviate significantly from value 1, damping of the low-

pass filter does not exhibit significant values. But, starting with the limit frequency of the low-pass filter, the damping rises sharply, so that the unavoidable resonance step-ups of the mechanical frequency response virtually exert no more influence.

[0028] The delay of the acceleration signal $\underline{b}_m$ by the measurement transfer function $F_g(P)$ and the delay additionally caused by the low-pass filter are entirely eliminated by the signal $\underline{y} = \underline{b}_{Em} \bullet F_H(p)$ at the output of the high-pass filter 3 in the frequency response in question of the control loop formed by means of the synthesized signal $\underline{z}$.

[0029] The system and method of the invention is further described by the balance of elements shown in Figure 1. The first-order delay element 5 (see Figures, 1, 2, 3, and 4) with amplification V_R and time constant T_E describes the delayed reaction of the armature current $\underline{i}_a$ to change in voltage at the input of the delay element.

[0030] Fig. 2 illustrates a control system for a plurality of electric drive types, in accordance with a first alternative embodiment of the invention. In Fig. 2, the output voltage of the pulse inverter which feeds the armature winding of the drive is derived directly from a two-point control loop, on the principle of the discrete-time switching condition control with a clock frequency $f_A = 1/T_A$ in the 100-kHz range. Consequently, in Figure 2, the controller 4 is replaced by the two-point element 6, a scanning element 7 with scanning frequency $f_A = 1/T_A$, and a zero-order holding element 8. Amplifications V and -V in the two-point element 6 take the ratio of converter output voltage to rated voltage of the machine into account. The scanning element 7 and the zero-order holding element 8 allow for the effect of discrete-time switching condition control. In this embodiment of the system and method of invention, the limit frequency selected for the low-pass filter 2 with low-pass transfer function $F_T(p)$ is to be low enough that no self-excited oscillations occur in the two-point control circuit for synthesized signal $\underline{z}$.

[0031] Should it occur, as it frequently does, in practical applications that the connection

between the measured substitute acceleration signal $\underline{b}_{Em}$ and the measured acceleration signal $\underline{\alpha}_m$ is only incompletely described by the equation $\underline{\alpha}_m = F_g(p) \bullet \underline{b}_{Em}$ prove to be a source of disturbance for the quality of the two-point cascade control, the system and method the invention may be expanded. This expansion is characterized by the block shown diagram in Figure 3. In this instance, the transfer function $F_M(P)$ 9 describes the mechanical frequency response between the surface of the armature when it is in motion (which is engaged by the thrust of the electrical drive 20), and the accelerometer which is positioned on the surface of the armature, and which measures its acceleration.

[0032] The relationship between the substitute acceleration signal $\underline{b}_{Em}$ and the measured acceleration $\underline{\alpha}_m$ is accordingly expressed as $\underline{\alpha}_m = F_M(p) \bullet F_g(p) \bullet \underline{b}_{Em}$. This mechanical frequency response with transfer function $F_M(p)$ 9 (see Figures 3 and 4) is now taken into account in that the high-pass filter 3 with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$ is replaced by a modified high-pass filter 10 with modified high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p) \bullet F_M(p)$. It is advisable in this process not to set the limit frequency of the low-pass filter 2 with low-pass transfer function $F_T(p)$ until the high-pass filter 3 with high-pass transfer function $F_H(p)$ has been replaced by modified high-pass filter 10 with modified high-pass transfer function $F_h(p)$.

[0033] Should the transfer function $F_M(p)$ have a plurality of polar and/or zero positions, development of the high-pass filter 10 with modified high-pass transfer function $F_h(p)$ is found to be very costly. In order to reduce this cost in development of this high-pass filter 10, the system and method of the invention may be further modified as shown in Fig. 4.

[0034] Fig. 4 illustrates a control system for a plurality of electric drive types in accordance with a third alternative embodiment of the invention. In Fig. 4, the transfer function $F_M(p)$ 9 of the mechanical frequency response of Fig. 3 has been separated into two components, $F_{M,REST}(P)$ and $F_O(p)$. $F_O(p)$ is defined as follows:

$$F_0(p) = \frac{(1 + p \bullet T_\mu) \bullet (1 + 2 \bullet D_v \bullet p \bullet T_v + p^2 \bullet T_v^2) \bullet \ldots}{(1 + p \bullet T_i) \bullet (1 + 2 \bullet D_j \bullet p \bullet T_j + p^2 \bullet T_j^2) \bullet \ldots}$$

[0035] This part allows for one or more poles and/or zero positions with particularly high values of T_μ, T_v, T_i, or T_j. The transfer function of the mechanical frequency response may be described as follows:

$$F_M(p) = F_0(p) \bullet F_{M,Rest}(p), \text{ with}$$

$$F_{M,Rest}(p) = F_M(p) \bullet F_0^{\,1}(p).$$

[0036] The mechanical frequency response with transfer function $F_M(p)$ 9 is now taken into account only in approximation in that the high-pass filter 3, with high-pass transfer function $F_H(p) = F_T(0) - F_T(p) \bullet F_g(p)$ is replaced by a modified high-pass filter 11 with modified high-pass transfer function $F_{h*}(p) = F_T(0) - F_T(p) \bullet F_g(p) \bullet F_0(p)$. It is advisable not to determine the limit frequency of the low-pass filter 2 with low-pass transfer function $F_T(p)$ in this process until the high-pass filter 3 with high-pass transfer function $F_H(p)$ has been replaced by modified high-pass filter 11 with modified high-pass transfer function $F_{h*}(p)$.

[0037] The present invention has been described with reference to certain exemplary embodiments thereof. However, it will be readily apparent to those skilled in the art that it is possible to embody the invention in specific forms other than those of the exemplary embodiments described above. This may be done without departing from the spirit and scope of the invention. The exemplary embodiments are merely illustrative and should not be considered restrictive in any way. The scope of the invention is defined by the appended claims and their equivalents, rather than the preceding description.

[A system and method for the generation of a partly synthesized high-quality signal for acceleration of an armature of an electric drive]

Abstract of the Disclosure

A system and method for controlling the acceleration of an armature of an electric drive by generating a high quality acceleration error correction signal $\underline{z}$, the system comprising an accelerometer for obtaining a measured armature acceleration value $\underline{b}_m$, which is equal to the product of a true armature acceleration α, and an acceleration measurement transfer function $F_g(p)$, and means for obtaining a measured acceleration signal, $\underline{b}_{Em}$, which is generated from a measured substitute acceleration signal $\underline{b}_E$. $\underline{b}_m$ and $\underline{b}_{Em}$ are scaled such that the relationship of $\underline{b}_m = \alpha \bullet F_g(p) = \underline{b}_{Em} \bullet F_g(p)$ is satisfied. The measured armature acceleration signal $\underline{b}_m$ is filtered with a first filter transfer function of $F_T(p)$, and the measured acceleration signal $\underline{b}_{Em}$ is filtered with a second filter transfer function of $F_H(p)$. The first and second filter outputs are combined to form the partly synthesized high quality acceleration error correction signal $\underline{z} = \underline{b}_m \bullet F_T(p) + \underline{b}_{Em} \bullet F_H(p)$.